ADDRESS

Delivered by the President, Edwin Dunkin, F.R.S., on presenting the Gold Medal of the Society to William Huggins, D.C.L., LL.D., F.R.S.

Gentlemen,

You have already been informed in the Annual Report, just read, that the Council have awarded the Gold Medal of the Society to Dr. William Huggins for his researches on the motions of stars in the line of sight, and on the photographic spectra of stars and comets. It now becomes my pleasing duty to explain to you briefly, in a general manner, the principal grounds by which the Council have been influenced in coming to their decision.

Before doing so, however, perhaps I may be permitted to remark that no one can possibly refer to the printed list of our medallists without being impressed with the wideness of scope available to the astronomical inquirer, as illustrated by the great diversity of subjects for which the medal has been awarded by the respective Councils in past years. A glance at the names contained in the printed list shows clearly that the medals of the Society have been presented to astronomers without regard to nationality or to subject, for their original researches either in the mathematics, the ordinary observing labours, or in the literature of astronomy. For instance, I do not find that profound researches on the theories of the movements of the members of the Solar System, or on kindred mathematical subjects, have been more recognised than those relating to important tabular deductions from meridian or equatorial observations, to the original discoveries of planets and comets, or to many other miscellaneous subjects in the more popular branches of the science. On the contrary, since the first award in 1823 to the present time, original inquirers in all branches of astronomy have been found worthy recipients of our medal, a sufficient evidence of the strict impartiality of the Council. But it must be borne in mind that this, the highest scientific honour that the Society can bestow, has never been presented to anyone before his claims have been well weighed by those who, for the time being, have been the Society's representatives. The chief object of the Council, so far as my experience goes, has always been the endeavour to recognise the original works of astronomers generally whenever

any specially high merit is exhibited, or a definite advance on some point in astronomy is made; and I believe in a remark made by Sir George Airy, that "Scarcely ever has it occurred that in looking back to the award of our medals we could say that any important subject had been omitted which ought to have been taken into consideration, or that a better choice could have been made than that which we have made."

As you are all doubtless aware, the Society's gold medal was awarded in 1867 to Dr. Huggins, jointly with Dr. W. Allen Miller, for their researches in astronomical physics. The grounds for this award are most ably and eloquently given in the address of the President, Professor C. Pritchard, and I consider that I cannot do better than refer you to that address, not only for numerous details connected with the labours of these gentlemen, given with all that earnestness of language of which the author is so consummate a master, but also for an interesting, though brief, account of the progress of spectrum analysis as applied to the examination of the physical constitution of the heavenly bodies from the time when Dr. Wollaston, in 1802, first observed a few of the principal lines in the solar spectrum. I thus refer you to Professor Pritchard's address, as, in the few remarks which it will be my duty to make, I shall naturally confine myself to those observations of Dr. Huggins made subsequently to 1867, and more particularly to the special subjects named in the award, referring to his original experimental researches relating to his method for determining the motions of stars in the line of sight, and to his successful photographs of the spectra of stars and comets.

Although Dr. Huggins's first published memoir on his method of determining the relative radial motions of the Earth and stars appeared in 1868, the subject had previously occupied the attention of himself and Dr. Miller so early as 1862; for while engaged in that year on the comparison of the bright lines of terrestrial substances with the dark lines in the spectra of a few of the principal stars, with the object of obtaining information on their chemical composition, their thoughts were also directed to this question of radial stellar motion, for Dr. Huggins has remarked that at the time they were fully aware that "if the stars were moving towards or from the Earth, their motion, compounded with the Earth's motion, would alter to an observer on the Earth the refrangibility of the light emitted by them, and consequently the lines of terrestrial substances would no longer coincide in position in the spectrum with the dark lines produced by the absorption of the vapours of the same substances existing in the stars." (*Phil. Trans.*, 1868, p. 529.) Owing, however, to the insufficiency of the apparatus in these early and delicate experiments, the first results were, on the whole, of a negative character, though enough evidence was obtained to show that better instrumental means only were required to test the method to some definite conclusion. Suffi-

cient, however, was done in the early part of 1868 to enable Dr. Huggins to present, with some confidence, to the Royal Society some observations on a small change of refrangibility which he had observed in a line in the spectrum of *Sirius* when compared with a line of hydrogen. This very small displacement indicated that the star was receding from the Earth in the direction of the line of sight with a velocity of about twenty-nine miles per second.

Dr. Huggins does not claim in any way to be the first to suggest the theoretical idea of using the spectroscope for determining the effects produced by the radial motions of the stars; for I observe that in his memoir, previously quoted, he refers to the researches of Doppler, Fizeau, Clerk-Maxwell, and others who have considered this question. The researches of these physicists, however, all differ in many important respects from those of Dr. Huggins, inasmuch as they refer generally either to the theoretical explanation of the differences of colour usually found in binary stars, or to certain experiments on the influence of the motion of a source of light upon the refrangibility of its rays. The following extract from a letter, addressed to Dr. Huggins in 1867 by the late Professor Clerk-Maxwell, refers specially to M. Fizeau's valuable memoir in the *Annales de Chimie et de Physique*, Feb. 1860. After explaining his own experiments on the influence of the motions of the heavenly bodies on the index of refraction of light, he has stated that "On the other hand, M. Fizeau has observed a difference in the rotation of the plane of polarisation according as the ray travels in the direction of the Earth's motion or in the contrary direction, and M. Ångström has observed a similar difference in phenomena of diffraction. I am not aware that either of these very difficult observations has been confirmed by repetition. In another experiment of M. Fizeau, which seems entitled to greater confidence, he has observed that the propagation of light in a stream of water takes place with greater velocity in the direction in which the water moves than in the opposite direction, but that the acceleration is less than that which would be due to the actual velocity of the water, and that the phenomenon does not occur when air is substituted for water. This experiment seems rather to verify Fresnel's theory of the ether; but the whole question of the state of luminiferous medium near the Earth, and of its connection with gross matter, is very far as yet from being settled by experiment." (*Phil. Trans.*, 1868, p. 535.)

Doppler, in 1841, contended that, as the impression received by the eye and ear is not the result of the strength and period of the waves of light and sound, but that it is rather determined by the interval of time occupied by them in falling upon the eye or the ear of the observer, it follows "that the colour and intensity of an impression of light, and the pitch and strength of a sound, will be altered by a motion of the source of the light or of the sound, or by a motion of the observer, towards or from

each other." By this hypothesis Doppler conceived that he could account for the remarkable variations of colour observed in binary stars. I do not perceive, however, that he or the other physicists, who have investigated the subject, had suggested any trustworthy practical method of observation, by which the absolute amount of approach or recess of stars could be satisfactorily measured. It appears to me, therefore, that this great advance in the subject was reserved for Dr. Huggins, for the undoubted success of the method contrived by him cannot fail to be acknowledged by the results he has given, first in his memoir of 1868, and repeated in that of 1872; results which have been amply confirmed year by year from observations made at the Royal Observatory, Greenwich, at the Observatory of Potsdam, and at other places. To him, therefore, most assuredly belongs the credit of being the first astronomical physicist who gave practical life to the subject, and made the method of observation completely efficient, by which he has added a new element to our knowledge of the system of the universe.

But, gentlemen, I wish you clearly to understand that, successful as Dr. Huggins has been in contriving a method of observation which has been easily followed by independent observers, this success has not been gained without great perseverance on his part, and a determination not to be daunted by any apparent failure. From the first he was evidently convinced in his own mind of the practicability of the method, and that ultimately he would attain sufficiently trustworthy results, which would enable him to announce with confidence that he had really succeeded in measuring the amount of displacement of one of the principal lines in the spectrum of a star, and to determine from that displacement the approximate motion of that star in the line of sight. In experiments of this delicate nature, and probably of most others of a similar kind, we may naturally suppose that the observer, at the beginning of his experiments, is troubled with all sorts of difficulties; and when we consider that so much depends on the steadiness of the atmosphere, or on the accurate adjustment of the spectroscope, the telescope, and other parts of the apparatus employed, can there be any wonder that the first observations are frequently of a negative character? However, sufficient was shown by the early comparisons made by Dr. Huggins to prove that none of the stars, the lines in the spectra of which had been carefully compared, were moving in the direction of the visual ray, relatively to light, equivalent to the displacement of a line through a space equal to that which is observed between the components of Fraunhofer's D. This observation alone was a great advance. But, as I have before remarked, it was not till 1868 that Dr. Huggins, in his communication read before the Royal Society on May 14 of that year, was able to indicate with tolerable certainty a marked, though smaller, displacement of the F line in the spectrum of *Sirius*, which he considered to be the effect pro-

duced by the relative motions of the Earth and Star in the line of sight. As an illustration of the question of what are some of the difficulties experienced in these delicate observations, I think it will be appropriate to quote here the words of Dr. Huggins himself. He says:—"The chief difficulties which I have had to encounter have arisen from the unsteadiness of our atmosphere. There is sufficient light from stars of the first and second magnitude for the large spectroscope, and so far as the adjustments of the instrument are concerned, the lines in the spectra of the stars would be well defined. Unless, however, the air is very steady, the lines are seen too fitfully to permit of any certainty in the determination of coincidences of the degree of delicacy which is attempted in the present investigation. I have passed hours in the attempt to determine the position of a single line, and have then not considered that the numerous observations which I had obtained were possessed, even collectively, of sufficient weight to establish with any certainty the coincidence of the line with the one compared with it." (*Phil. Trans.*, 1868, p. 546.)

All the observations, prior to 1870, were made with the Alvan Clark Refractor of 8 inches aperture and 10 feet focal length, mounted equatorially, and fitted with a clock-movement, which carried the instrument very smoothly. In 1870, the Royal Society placed at the disposal of Dr. Huggins their large Equatorial, constructed by Messrs. Grubb & Son. This instrument is provided with a tube and object-glass of 15 inches aperture, and 15 feet focal length, and also with a second tube containing a speculum of 18 inches diameter. Either of these tubes could be attached, when required, to the declination-axis of the equatorial mounting. In 1882 the instrument was taken down, and remounted in the early part of the following year, with considerable improvements in the mounting of the tubes, which are now attached to two separate declination-axes, the one moving within the other. The two tubes can now be moved in declination independently of each other, and the one not in use can be turned away so as not to be in inconvenient positions. Both are carried by the clock-motion.

The spectroscope which Dr. Huggins had constructed in 1866 for the special objects of his research was furnished with three prisms of 60° of very dense flint-glass, through which the solar lines were very distinctly seen. To obtain a separation of the lines sufficient for his purpose, he found it necessary to employ an eye-piece magnifying ten or twelve times. The stellar lines were not, however, seen in the continued steady manner required for the accurate measurements of the small displacements observed. To obviate this inconvenience, and to ensure success in his observations, Dr. Huggins resolved to employ a larger number of prisms and a smaller magnifying power. He was fortunate in having in his possession two very fine direct-vision prisms on Amici's principle, which induced

him to attempt to combine in one instrument several simple prisms, with one or two compound prisms, which gave direct vision. By this combination of prisms an instrument was devised possessing several not unimportant advantages; but in 1868, after Dr. Huggins's first series of comparisons, an apparatus, superior in many respects to that described in his memoir (*Phil. Trans.* 1868, p. 536), was constructed and afterwards employed in his more recent observations of the displacement of the lines in stellar spectra due to the motions of the stars in the line of sight, and for other spectroscopic work.

For a further detailed account of the peculiar features of the various contrivances adopted by Dr. Huggins in his observations, I must refer you to his original memoirs for these, and for many other interesting particulars, relating to the methods employed, and the many difficulties experienced, in this delicate research, which have led him on step by step towards the successful completion of his original design.

The stars selected by Dr. Huggins in his earlier experiments were mostly those of the first magnitude, including *α Orionis*, *Sirius*, *Aldebaran*, and *Castor*, of all of which comparisons of their spectra were made before 1868; but definite results were only obtained from those of *Sirius* when compared with the F hydrogen line. For my present purpose, therefore, it will be a sufficient example if I confine my remarks wholly to that star, whose resulting radial motion was the first confidently announced as a proof of the adequacy of the method of comparison. The subject was soon taken up at other Observatories, and its principle, for the most part, confirmed.

As Dr. Huggins and Dr. Miller had previously concluded that the strong lines in the spectrum of *Sirius* were due to the presence of hydrogen, the F line was used generally in the comparisons. At the time when the observation of the displacement of this line was made by Dr. Huggins, the amount of the change of refrangibility was in wave-length 0·109 millionth of a millimetre. Assuming the velocity of light to be 185,000 miles per second, and the wave-length of F 486·50 millionths of a millimetre, it was found that the observed displacement of this line in *Sirius* would indicate a motion of recession from the Earth of 41·4 miles per second. When this observation was made, it appeared that the Earth was moving with a velocity of about 12 miles per second, from which it has been inferred that, of the combined recession of 41·4 miles per second between the Earth and the Star, 29·4 miles per second may be attributed to the motion of *Sirius* in the line of sight at that period.

Fortified with new instrumental means of the highest order, Dr. Huggins resumed his inquiry in the spring of 1872, and during a few nights sufficiently fine for these delicate comparisons, he was able to make several series of measures of the amount of displacement of the F line in the spectrum of *Sirius* with the corresponding line in the spectrum of hydrogen. This set of

observations completely confirmed the former conclusion that the star was receding from the Earth, but with a much smaller velocity; for whereas in 1868 the observed absolute radial motion of the star was found to be 29·4 miles per second, the motion determined in 1872 was from 18 to 22 miles per second. Dr. Huggins has observed on this apparent diminution of velocity that "the difference of this estimate, which is probably below rather than in excess of the true amount, from that which I formerly made may be due in part or entirely to the less perfect instruments then at my command. At the same time, if *Sirius* be moving in an elliptic orbit, as suggested by Dr. Peters, that part of the star's proper motion which is in the direction of the visual ray would constantly vary." More recent observations made at the Royal Observatory would seem to confirm this apparent change of velocity, and that the original estimate in 1868 was at the time not far from the truth. It is remarkable that a nearly constant diminution of the recession has been recorded in the Greenwich Observations from year to year, till at the present time a considerable approach towards the Sun is indicated.*

In addition to *Sirius*, the stars found by Dr. Huggins in 1872 to be receding from the Sun are *Rigel*, *α Orionis*, *Castor*, *Regulus*, and β, γ, δ, ϵ, and *ζ Ursæ Majoris*, while those found to be approaching the Sun are *Pollux*, *α Ursæ Majoris*, *Arcturus*,

* Through the courtesy of the Astronomer Royal, I am enabled to give in the following table the mean concluded radial motion of *Sirius*, observed at the Royal Observatory at each opposition. The measures from 1875 to the spring of 1877 were obtained with the old ten-prism spectroscope, and extended over the period from December 22, 1875 to March 17, 1877. The other measures were all obtained with the half-prism spectroscope. The years given in the first column refer to the winter season common to both years; for instance, 1877–78 means that the observations were made during the winter from November 1877 to March 1878.

Motion of Sirius in the Line of Sight, from Observations made with the Spectroscope at the Royal Observatory, Greenwich.

Opposition of	Number of Nights.	Number of Measures.	Mean Concluded Motion.
1875–76 and 1876–77	4	8	+21·1 miles per sec.
1877–78	3	8	+23·0 „
1879–80	3	10	+15·1 „
1880–81	2	4	+11·3 „
1881–82	5	22	+ 2·1 „
1882–83	3	18	− 4·7 „
1883–84	13	43	−19·4 „
1884–85	2	8	−21·5 „

In the last column the sign + denotes recession from the Sun, and the sign − approach towards the Sun.

a Lyræ, and *a Cygni*, omitting many others which indicate either recession or approach, but which had been deferred for further observation.

I have no doubt that many of the Fellows will be interested to learn that observations for the determination of the motions of stars in the line of sight now form a most important branch of the daily work in the Physical department of the Royal Observatory whenever the state of the sky permits. The results have been communicated to the Society, and they appear annually in the *Monthly Notices*. In one year, 1883, the observed amount of the displacement of usually the F or b_1 lines is given for 46 stars, of many of which the observations were made on several nights during the year. The total number of measures were 310.* The absolute results of approach or recession of corresponding stars deduced by Dr. Huggins and at the Royal Observatory have been compared by the present Astronomer Royal. The agreement between the two series of concluded values is most satisfactory, and, considering the great delicacy of the observations, the discordances are not greater than might have been expected. Some of these comparisons have been communicated to the Society by Mr. Christie, who has remarked that, notwithstanding the difficulty of observation, "it is gratifying to find that, out of the list of 21 stars which have been observed, both by Dr. Huggins and Mr. Maunder, there are only two cases of discordance, as will be seen from the table; and for both of these stars Dr. Huggins has expressed himself as dissatisfied with his observations; whilst the Greenwich results for these stars rest on too few observations at present." (*Monthly Notices*, vol. xxxvi. p. 316.) The observations of these and other stars made at Greenwich in subsequent years to the date of that communication give also generally accordant results. (*Monthly Notices*, vol. xxxviii. p. 507.)

I cannot conclude this portion of my address more appropriately than by giving the independent testimony of my late revered friend, Mr. Spottiswoode, on presenting the Rumford Medal to Dr. Huggins at the anniversary meeting of the Royal Society on November 30, 1880. I give it in his own words: "Dr. Huggins has determined the radial component of the velocity of the heavenly bodies relatively to our Earth, by

* Since writing the above, I find from the Council Report of the Proceedings of the Royal Observatory that these numbers were far exceeded in 1884, when 731 measures of displacement of either the F or b lines were observed, consisting of 674 measures of the F line in the spectra of 48 stars, 49 of the b lines in the spectra of 12 stars, and eight of the F line in the spectrum of the great nebula in *Orion*. In addition to these measures, 132 comparisons of the hydrogen or magnesium lines, with the corresponding lines in the spectrum of he Moon, were made as a check on the general accuracy of the concluded tesults of the absolute motions of the stars in the line of sight. Several measures of the displacement of the F and b lines in the spectra of *Venus* and *Mars*, and some observations of the relative displacement of the same lines at the east and west limbs of *Jupiter*, were also made for the same purpose.

means of the alteration of the refrangibility of certain definite kinds of light which they emit, or which are stopped by their atmospheres. The smallness of the alteration corresponding to a relative velocity comparable with the velocity of the Earth in its orbit makes the determination a matter of extreme delicacy. But as early as 1868, he had obtained such trustworthy determinations, that he was able to announce before the Royal Society that *Sirius* was receding from our Solar System with a velocity of about 29·4 miles per second. In a paper presented to the Royal Society in 1872, he has given the results obtained for a large number of stars, and has shown that some are receding and some approaching, and that there seems to be a balance of recession in those parts of the heavens, from which we have reason, from the observed proper motions, which of course can only be transversal, to conclude that the Solar System is receding, and a balance in favour of approach in the opposite direction; while yet it does not appear that the motion of the Solar System would alone account for the whole of the proper motions of the stars in a radial direction.

"The same inquiry was extended to the nebulæ, the spectrum of which consists of bright lines, and in this case it presented greater difficulties. As those nebular lines, which appear pretty certainly to be identifiable with hydrogen, are too faint to be employed in the investigation, and the others are not at present identified with those of any known element or compound, he was obliged to avail himself of a coincidence between the brightest nebular line and a line of lead. But as the coincidence is probably merely fortuitous, the results give only the *differences* of approach or recess of different nebulæ. The observations seem to show that, so far as has been observed, the nebulæ are objects of greater fixity as regards motion in space, than the stars."

Though I believe that it is no part of my duty, on the present occasion, to refer to any other researches of Dr. Huggins than those contained strictly within the grounds of the award, still, I consider that it is only proper that I should draw your attention to the subjects, at least, of some of his more important contributions to astronomical physics, which have been published since 1867. My remarks on them must, however, be very brief, but the full details of each will be found either in the *Philosophical Transactions* or *Proceedings* of the Royal Society, and in some other publications.

One of the first investigations which Dr. Huggins undertook after the erection of the Royal Society Equatorial, was the determination of the true character of the bright lines in the spectra of the nebulæ, one of which was found to be probably coincident with that of nitrogen. His paper on his eye observations of the great nebula in *Orion* gives a detailed description of the character and position of the four bright lines: the first of which he was inclined to regard as probably due to nitrogen; the second

line was found to be a little less refrangible than a strong line in the spectrum of barium, but the substance to which it belongs is doubtful; while the third and fourth lines agree in position with two lines in the spectrum of hydrogen at F and near G. An estimation was made of the probable motion of the nebula in the line of sight; and if the amount of displacement of the first nebular line from the middle of the double line of nitrogen is correct, it would correspond to a velocity of 55 miles per second from the Earth, or, taking into account the Earth's orbital motion, a recession of 40 miles per second from the Solar System is indicated. From the difficulty of the observation, this result is not given by Dr. Huggins as final, as he remarks that it is possible that the first line in the spectrum of the gaseous nebulæ is not due to nitrogen at all, and that "in consequence of the uncertainty of the character of this first line, which is single, while that of nitrogen is double, this determination can now only be made by means of the comparison of the third line with that of hydrogen. The third line becomes very faint from the great loss of light unavoidable in a spectroscope that gives a sufficient dispersive power, and the comparison can only be attempted when the sky is very clear and the nebula near the meridian." Dr. Huggins's observations of the spectra of Brorsen's Comet, and Comet II. 1868, are highly important. The three bands observed in the spectrum of the latter comet, though in similar parts of the spectrum as the three bands in Brorsen's Comet, differed considerably from them in position and character. By a direct comparison in the instrument with the spectrum of olefiant gas, the bands of Comet II. 1868 were found to be identical in refrangibility, and in other respects, with the bands in the spectrum of carbon. The spectra of Comet I. 1871, and Encke's Comet in the same year, were also examined.

Soon after the great solar eclipse of August 18, 1868, you will remember that considerable interest was excited among physical astronomers when the information was received in England that the spectroscopic observations of the red prominences showed that their spectra were discontinuous, and that, at least, three bright lines were observed. This interest was much increased when the simultaneous announcement was made, at a meeting of the Académie des Sciences in the autumn of 1868, that M. Janssen on the day following the eclipse, and Mr. Lockyer a few weeks after, had each independently succeeded in viewing the spectrum of a prominence in daylight. Before this eclipse attempts were made by several observers for the same object, and among them Dr. Huggins, but without success. But shortly afterwards, having now some indication of the position of the bright lines, he saw the spectra of the prominences at once with a small spectroscope, with which they had been previously looked for in vain. The subject for some time continued to occupy his attention, and in the following

year he communicated to the Royal Society a short paper on a method of viewing the *forms* of the prominences by means of a wide slit, the method which has since been generally in use.

Time will not allow me to refer to other short, but interesting and valuable, papers of Dr. Huggins, as I must now proceed to the second subject named in the award, and consider some of his more recent labours on the photographic spectra of stars and comets.

The successful application of photography for the delineation of celestial objects has done much to give us a clearer conception of their peculiar features and constitution. My predecessor in this Chair, at the last anniversary meeting, had the gratifying duty of recognising, on the part of the Council, their just appreciation of the finest specimen as yet produced of the details of the great nebula in *Orion*, as photographed by Mr. Common, a work which, as Mr. Stone truly remarked, has "excited the admiration of all the astronomers who had an opportunity of inspecting it." But photography has also given us the beautiful representations of the lunar face, for which we are indebted to Mr. De La Rue and many others; of numerous celestial objects, including the photographs of the late Dr. Henry Draper, who was following, in some measure, the same line of research as Dr. Huggins; of the pictures of the great Comet of 1882 and the neighbouring stars, photographed at the Cape Observatory; and of some recent beautiful photographs of stars to the ninth magnitude, near θ *Orionis* and α *Aquilæ*, taken by Mr. Common. In Mr. De La Rue's photographs of the solar eclipse of 1860, we have undoubtedly the first recorded proof of the solar origin of the red prominences. No one can deny that these brilliant results, produced by the aid of the camera, are of the highest scientific importance, although I believe that the future of photographic astronomy will exhibit a history that will far transcend what has been accomplished in the past; and that the time will come—it may not be far distant—when astronomy will be enriched even with a photographic stellar atlas, which will contain not only a classified arrangement of the positions and magnitudes of the stars, but also an indication of the probable material elements of which the larger stars are composed. As the commencement of such a work, the photographic observations of the spectra of the stars, by Dr. Huggins, will always command an honourable place.

Although the subject of photographing the spectra of some of the principal stars was only systematically taken up by Dr. Huggins since the erection of the Royal Society equatorial, he had, nevertheless, planned a series of observations more than twenty years ago. With his friend and colleague, Dr. W. A. Miller, they had jointly succeeded in obtaining a photograph of the spectrum of *Sirius*, which was exhibited to the public on a screen at a lecture delivered at the Royal Institution in 1863. Previously to this the images of the stars had been photographed

as points, but the spectrum exhibited was the first instance that the rays of a star after dispersion were recorded upon a photographic plate. Though extremely interesting and valuable as a preliminary experiment, these photographs were not of sufficient clearness to be of scientific value, a defect which was partly due to the action of the driving-clock, which did not work with the required accuracy. The observations, therefore, were for a time discontinued.

In December, 1876, Dr. Huggins communicated to the Royal Society a preliminary "Note on the Photographic Spectra of Stars" (*Proceedings*, vol. xxv., p. 445), in which he states that he had recently resumed these experiments, using for his purpose the 18-inch speculum of the Royal Society equatorial, and that Mr. Howard Grubb had successfully applied to the clock the control of a seconds pendulum in electric connection with a sidereal clock, thus obtaining a sensibly uniform motion of the telescope. From this time the excellent series of photographs of stellar spectra, which Dr. Huggins has taken, may be said to have commenced. As an illustration of the effects of the improvement in his instrumental means, he was able, at this early stage of the inquiry, to give in the above paper an enlarged copy of the spectrum of *α Lyræ*, with a solar spectrum on the same plate, taken on the next day for comparison, the plate having been allowed to remain in the instrument during the interval. Seven strong lines in the spectrum of the star are exhibited on this early photograph, all slightly shaded at the sides. The two lines of least refrangibility coincide in position with two known lines of hydrogen in the solar spectrum. After the publication of this preliminary note, Professor H. Draper contributed two articles on the same subject to the *American Journal of Science*, the first in 1877 and the second in 1879.

The mapping of the photographic spectra of stars, as carried out by Dr. Huggins, is a research of great delicacy, as a perfect definition of the bands is absolutely necessary to allow of the accurate measurement of their respective wave-lengths. It may be supposed that to obtain this satisfactorily the most careful manipulation is requisite, when it is considered that the photographic plates are only $1\frac{1}{2}$ inch long by $\frac{1}{2}$ inch wide, and the length of the photographic spectrum between the lines G and P in the ultra-violet about $\frac{1}{2}$ an inch. The definition is usually very good, and the photographs can very easily be examined, and the position of the lines measured under a low-power microscope; and, though the solar spectrum on the plate is only $\frac{1}{2}$ an inch in length, about fourteen lines may be counted between the lines H and K. The delicacy of the observation arises partly on account of the small quantity of light at the disposal of the observer, and partly to the extreme care required to obtain accurate comparisons of the star spectrum with the spectra of known substances, in order to ascertain whether the presence or absence of such and such substances may be detected in the stars. The general conclusion, from the discussion of the

different spectra, appears to show that the stars may be arranged in a connected series, the various types passing from the class of white stars, through stars more or less resembling our Sun, to the stars which shine with an orange or red light. Dr. Huggins suggests that these types of spectrum probably indicate the relative ages of the stars, or at least their relative temperature.

In Dr. Huggins's complete memoir, read before the Royal Society on December 18, 1879 (*Phil. Trans.*, 1880, pp. 669–690), special notes are given on the peculiarities of the following stars in the first or white group, *Sirius*, *η Ursæ Majoris*, *Spica*, *α Aquilæ*, *α Cygni*, and *α Lyræ*. Photographs were also obtained of several other stars, but owing to the unfavourable state of the atmosphere when they were taken, a description of their spectra is deferred. "The photographs present a spectrum of twelve very strong lines. Beyond these lines a strong continuous spectrum can be traced as far as S, but without any further indication of lines. The least refrangible of these lines is coincident with the line γ of hydrogen near G. The next line in order of greater refrangibility agrees in position with *h* of the solar spectrum. The third line is H; K, if present at all, is thin and inconspicuous. The nine lines which follow do not appear to be coincident with any of the stronger lines of the solar spectrum. These lines appear to be common to all the stars of this class, though it may be that some of the more refrangible lines are sometimes absent." * The usual time of exposure with sensitive gelatine plates was from fifteen minutes to two hours; but in the more recent trials with still more sensitive plates, the period of exposure has been reduced.

In a photograph of the spectrum of *Rigel*, taken on January 3, 1880, all the typical lines can be detected, and they are broader than those found in the spectrum of *α Cygni*, but not so broad as the lines in that of *Spica*. There is also a suspicion of lines beyond the typical group, and of two other lines between α and γ.

Taking *Arcturus* as an example of another type, it is found that it has a photographic spectrum containing a great many lines from *b* to G, and the whole spectrum is crowded with lines as seen in the solar spectrum, which makes a great dissimilarity between its spectrum and that of the class of white stars. Twenty-one of the stronger of these lines have been carefully measured and mapped, and several of them agree in position with corresponding lines in the solar spectrum. Dr. Huggins gives the wave-lengths of eighty-one lines in the spectrum of this star. On the more refrangible side of *h* the appearance of a bright band is seen which suggests a bright line,

* The observed wave-lengths of the twelve typical lines are:—

	W.L.		W.L.		W.L.
H	4340	β	3834	ζ	3730
h	4101	γ	3795	η	3717·5
H_1	3968	δ	3767·5	θ	3707·5
α	3887·5	ϵ	3745·5	ι	3699

on which Dr. Huggins remarks that "After a careful examination of the two negatives which I have of this star, and of positions taken from them, I have come to the conclusion that this appearance is really due to the absence of the finer lines which probably crowd the other parts of the spectrum, though they are too fine and close to be seen separately in the photographs." Beyond K there is a strong contrast in the character of the lines, for they are arranged more or less in triple and other forms of grouping, the lines being much wider and more intense. All the principal lines in the crowded portion of the spectrum have been measured and inserted in the map accompanying the original memoir. I have lately had an opportunity of examining several of the original photographs in each type, and I am glad that I am able to give my unbiassed testimony to the great dissimilarity of the lines in the spectra of the two classes of stars, and also to the exquisite definition of the lines in the photographs of both the solar and stellar spectra.

The spectrum of *Aldebaran*, a pale red star, is also crowded with lines. About fifty of the stronger lines can be measured. In the more refrangible part of the photographed portion of the spectrum the lines are more numerous than in the other portion, and of a different character, being broader, more intense, and apparently more diffused at the edges. The spectrum of *Capella*, though a white star, is a remarkable one, containing a large number of lines, on which Dr. Huggins has remarked that the photographs "exhibit a spectrum from F to beyond S, which so closely resembles the solar spectrum that a photograph of this star would, at first sight, be taken for a solar one," and that this general resemblance of the spectrum of this star with the solar spectrum would seem to indicate that *Capella* is in the same stage as that in which our Sun is.

In addition to these stellar photographs, Dr. Huggins has also taken successful photographs of the spectra of *Venus*, *Mars*, and *Jupiter*, together with a broad daylight spectrum for comparison. They, however, fail to show any additional absorption lines, or any modifications of the solar light in the photographic part of the spectrum. Photographs of the light of the Moon from limited areas of the lunar surface have been taken under different conditions of illumination, and also during partial eclipses of the Moon.

The photographs have been examined and the lines measured by a micrometer attached to a low-power microscope. The measures were then reduced to wave-lengths by the help of solar and terrestrial spectra, with the assistance of Cornu's map of the ultra-violet part of the spectrum, and of Mascart's determinations of the wave-lengths of cadmium. The spectra of *Sirius*, η *Ursæ Majoris*, *Spica*, α *Aquilæ*, α *Lyræ*, α *Cygni*, and *Arcturus*, admit of easy comparison by reference to the map which is laid down on the scale of that of Cornu.

I have already briefly referred to Dr. Huggins's direct eye-observations of the spectra of several comets and to the im-

portant deductions he has obtained from them relating to their physical constitution, but I am now desirous to draw your particular attention to a successful photograph of the spectrum of Comet I., 1882 (Wells), in which the cometary bands differ considerably from those observed in the spectra of previous comets. These bands are exhibited with great clearness in the photograph, an enlarged copy of which may be found in the *Proceedings*, R. S., vol. xxxiv. p. 149. This photograph was taken through one half of the slit on the evening of May 31, 1882, with an exposure of an hour and a half. For the convenience of accurate comparison a spectrum of α *Ursæ Majoris* was taken on the same plate through the other half of the slit. It shows a strong continuous spectrum without the appearance of any of the Fraunhofer lines, extending from about F to a little beyond H. The spectrum differs greatly from that of Comet I. 1881, as also from the spectra of the comets (about twenty) which had been previously examined spectroscopically, and contains bright lines indicating the presence of vapour of sodium, and also some other bright lines and groups of lines. "The continuous spectrum which extends from below F to a little distance beyond H contains at least five brighter spaces, which are doubtless groups of bright lines, though it is not possible in the photograph to resolve them into lines. These places of greater brightness can be traced beyond the border of the continuous spectrum on the side which corresponds to the coma of the comet on the side next the Sun. The light from this part of the comet gave a very much fainter continuous spectrum, for on the photographic plate it appears to be almost wholly resolved by the prisms into these bright groups. One or two fainter groups are suspected to be present, but they are too indistinct to admit of measurement." The beginning and ending of the bright groups are very faint, and the estimated brightest parts only are capable of being measured.

In the photographic spectrum of the great nebula of *Orion*, obtained on March 7, 1882, after an exposure of forty-five minutes, may be noticed five bright lines, as well as a narrower continuous spectrum which Dr. Huggins considers may be due to stellar light. In his previous eye-observation of the spectrum of this nebula he had found four bright lines, the brightest being coincident with the less refrangible component of a strong double line in the spectrum of nitrogen. The second line has a wave-length of 4957 of Ångström's scale, the third and fourth lines being coincident with, as I have already stated, two lines of hydrogen. In the photograph these lines are faint, but they can be satisfactorily recognised and measured. In addition to these the photographic spectrum shows a comparatively strong line in the ultra-violet, corresponding nearly to ζ of the typical spectrum of white stars.

Dr. Huggins's successful application of photography to the subject of these inquiries is now so far acknowledged to be an important astronomical achievement that it is hoped that others will follow his example. But any attempts to follow in his

footsteps will certainly end in failure unless the observer is in possession of instruments of the highest class as well as the necessary zeal for the work. This inquiry into the probable physical constitution of individual stars ought not to be considered completed by Dr. Huggins's experiments, but rather it should be looked upon as the commencement of a research to include the examination and classification of the spectra of all the large stars in both hemispheres. That this will be done sometime in the future I have not the least shadow of a doubt. In the meanwhile we are all able to appreciate the excellent work which our Foreign Secretary has initiated and accomplished.

In conclusion, let us not suppose for one moment that the reliable information we possess at present, relating to the peculiar apparent radial motions and physical constitution of the heavenly bodies, has been obtained without considerable personal and anxious thought on the part of those valued contributors, of different nationalities, who have devoted their time and energy in the prosecution of other delicate researches in spectroscopic astronomy, besides those which form the special subjects of our remarks to-day. I am certain that much early apparent want of success has been felt from time to time by all those physical astronomers who have so nobly enriched our knowledge in this interesting branch of astronomy, since the modern application of the spectroscope to the analysis of the light of the Sun, comets, stars, and nebulæ—a subject of investigation which was first brought prominently into notice by the publication of the remarkable researches of Kirchhoff and Bunsen in the *Memoirs* of the Academy of Berlin, 1861. Among the anxieties to which an observer is liable in delicate observations of this kind, he must always look forward to the many difficulties that are certain to arise at the commencement of a new research, not the least of which are the doubts of ultimate success, or of the astronomical utility of the question under discussion; especially in one, as in the present instance, where the observer is required to possess a good knowledge both of the methods of astronomical observation and experimental chemistry. But where there is a determination to persevere in any well-planned investigation, it is always pleasant to note when, notwithstanding occasional failures, or it may be after seasons of great observing labour and energy on the part of the observer, the anxious inquirer after knowledge conquers all difficulties at last. It often happens in the earlier experiments, as we have previously noticed, that the observer is hampered either by insufficient instrumental means, or by difficulties in obtaining the correct adjustment of the apparatus employed, which, to command success, must be as perfect as possible. But when, by practice, he becomes acquainted with the capability of his instruments, these early difficulties are usually surmounted, and he goes on step by step in his research till he perceives a dawn of light approaching, and, not far distant, the long looked-for results, to attain which he has been so eagerly working, perhaps for years. We

can, in imagination, picture to ourselves the calm satisfaction of the observer when, after carrying on his delicate experiments for a long period, he finds that he is near the end of his self-imposed labours, so that he may soon be in a position to communicate to his colleagues the successful results of his experiments, and to receive from them possibly a due recognition of the scientific value of his work.

But, though we have just seen that difficulties and anxieties may reasonably be expected in all new, and to some extent novel, experiments, let it not be thought that all the early attempts in apparently unsuccessful investigations are entirely thrown away; but, as in the case of our Medallist, who, as we have seen, has had his failures as well as successes, let them rather lead the student of nature onwards to further trials, and, if sincere in his work, he will eventually reap the reward of his zeal and perseverance. If Dr. Huggins, after his comparative failure in 1863 to obtain successful photographs of stellar spectra, or after his inability, at the same time, to decide to his satisfaction the true amount of displacement of a line in a spectrum of a star due to its motion in the line of sight, had looked with disfavour upon these interesting inquiries as far too difficult and delicate to be practically realised, and had consequently devoted his talents to other, and what at the time might have appeared more fruitful, branches of astronomy, we should not to-day have been able to recognise and admire the brilliant successes which he afterwards accomplished in his various investigations in astronomical physics, by the aid of increased experience and superior instrumental appliances.

And now, gentlemen, I have stated to you in a general manner the principal grounds which have led your Council to award the Medal to Dr. Huggins, and, after the remarks you have heard from me to-day, I am confident that you will coincide with their opinion that the important researches with which he has enriched our science are well deserving of that honour.

The President, then delivering the Medal to Dr. Huggins, addressed him in the following terms :—

Dr. Huggins,—

I have great pleasure in presenting you with this Medal which has been honourably awarded to you by the Council. I trust you will accept it as the highest acknowledgment of your valuable services to our science which it is in their power to bestow. This is not the first time that your devotion to astronomy has been recognised from this Chair, and I hope that it is not the last, for we still find you carrying on with success your important and delicate researches. May your health be long preserved, and may astronomy long continue to receive the benefit of your talents, which I have no doubt will be the means of still further adding to our present knowledge of the constitution of the universe.